

REINFORCING STAYING AND SWITCHING WHILE USING A CHANGEOVER DELAY

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Performance on concurrent schedules can be decomposed to run lengths (the number of responses before switching alternatives), or visit durations (time at an alternative before switching alternatives), that are a function of the ratio of the rates of reinforcement for staying and switching. From this analysis, a model of concurrent performance was developed and examined in two experiments. The first exposed rats to variable-interval schedules for staying and for switching, which included a changeover delay for reinforcers following a switch. With the changeover delay, run lengths and visit durations were functions of the ratios of the rates of reinforcement for staying and for switching, as found by previous research not using a changeover delay. The second directly assessed the effect of a changeover delay on run lengths and visit durations. Each component of a multiple schedule consisted of equivalent stay and switch schedules but only one component included a changeover delay. Run lengths and visit durations were longer when a changeover delay was used. Because visit duration is the reciprocal of changeover rate, these results are consistent with the established finding that a changeover delay reduces the frequency of switching. Together these results support the local model of concurrent performance as an alternative to the generalized matching law as a model of concurrent performance. The local model may be preferred when accounting for more molecular aspects of concurrent performance.

Key words: concurrent schedules, changeover delay, generalized matching law, local model, stay reinforcers, lever press, rats

An enduring goal of the experimental analysis of behavior is to understand choice, which often consists of engaging in Behavior 1 or engaging in Behavior 2. Alternatively, a simpler choice can be engaging in Behavior 1 or not engaging in Behavior 1. Reflection shows that an apparent choice of engaging in Behavior 1 or Behavior 2 can be decomposed to two simple choices: One simple choice is engaging in or not engaging in Behavior 1 and the second is engaging in or not engaging in Behavior 2. In this sense, then, all choice situations can be viewed as comprised of sets of choices of engaging in or not engaging in particular activities. While a third choice of not engaging in either behavior is available, it is not typically considered in traditional choice procedures and is omitted from the above discussion. If not engaging in either behavior is included as a choice, and one recognizes that some behavior is en-

gaged in when not engaging in either target behavior, the conclusion is unchanged; all choices can be viewed as engaging or not engaging in certain activities.

The simple choice of engaging in or not engaging in a particular behavior is functionally related to reinforcement for engaging in or not engaging in that behavior (MacDonall, 1999, 2000). Specifically, behaving (i.e., staying) at an alternative was reinforced according to a stay schedule of reinforcement, while not behaving at (i.e., switching from) the alternative was reinforced according to a switch schedule of reinforcement. Responding, that is, run lengths and visit durations, was a function of the ratio of the rates of reinforcement for staying and switching,

$$\log \frac{B_1}{C_2} = k_1 \log \left(\frac{Rt_1}{Rw_2} \right) + \log m_1, \quad (1)$$

where B_1 is behavior, either responses or time, at Alternative 1; C_2 is the number of times behavior stops at Alternative 1, that is, switches to Alternative 2; Rt_1 is the number of reinforcers obtained for staying at Alternative 1; and Rw_2 is the number of reinforcers obtained for switching to Alternative 2. The two fitted parameters are k_1 , which is behavioral sensitivity to differences in rates of reinforcement for staying and switching; and

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m_1 , which is the propensity (or tendency) to respond at Alternative 1.

The typical two-choice situation, usually arranged with concurrent schedules, comprises two simple choices: Behavior stays at Alternative 1 or switches, and behavior stays at Alternative 2 or switches (MacDonall, 1999, 2000). For example, concurrent variable interval (VI) 43 s VI 128 s consist of two simple choices: Staying at VI 43 s or switching, and staying at VI 128 s or switching. Each simple choice consists of a pair of stay and switch schedules that operates while at the associated alternative. One pair, that operates only while at Alternative 1, is a VI 43 s for staying at Alternative 1 and a VI 128 s for switching to Alternative 2. The other pair, that only operates while at Alternative 2, is a VI 128 s for staying at Alternative 2 and a VI 43 s for switching to Alternative 1. As this example illustrates, when concurrent schedules are decomposed to two pairs of stay and switch schedules, the values of the schedules are symmetric. That is, the value of the stay schedule at each alternative equals the value of the switch schedule at the other alternative.

Concurrent performance was synthesized by first presenting rats with several pairs of stay and switch schedules. Then, data from symmetric conditions were used to form ratios of the run lengths, visit durations, and reinforcers per visit for staying and switching (MacDonall, 1999, 2000). The composite performances were well described by the generalized matching law, which describes performance on concurrent choice procedures (Baum, 1974). This was noteworthy because rats were never exposed to the concurrent choice of responding at Alternative 1 or at Alternative 2; they were only exposed to the choice of responding at, or not responding at (switching from), one alternative.

A changeover delay (COD), which imposes a minimum time at an alternative before a response can be reinforced, was not used in the experiments that produced the composite concurrent performances. Most experiments that examined choice using concurrent schedules also used a COD. Consequently, it is not clear that the previous analyses apply to concurrent-choice experiments in general.

In the previous experiments that produced composite concurrent performances, the

COD was omitted because a COD changes the stay and switch contingencies in concurrent procedures. Consider a typical two-key concurrent procedure (Herrnstein, 1961). Without the COD, switching is immediately reinforced when, for example, the first response at the switched-to alternative is reinforced. In addition, theoretically, the last (stay) response at the switched-from alternative may be reinforced following a delay, which is the time taken to switch alternatives. Additional stay responses at the switched-from alternative, however, may also be reinforced following a greater delay. How many of these responses might be reinforced and how much they might be strengthened depends on the time it takes to switch alternatives: as the time to the first postswitch reinforcer decreases, more prior stay responses might be reinforced and the strengthening might be greater. The number of stay responses at the switched-from alternative that are reinforced and how effectively they are strengthened would also depend on the rate of stay responding at the switched-from alternative. As the rate of responding increased, more stay responses would be reinforced and the more the reinforcer for switching would strengthen them.

Using a COD affects the contingencies noted above and changes additional contingencies. Suppose a procedure uses a 5-s COD, which starts with the first response at the second alternative. Switching, which is completed by the first response at the second alternative, is reinforced following at least a 5-s delay between the first response at the second alternative and the response that produces the reinforcer. Because, commonly, several (stay) responses occur at the second alternative during the COD (e.g., Shahan & Lattal, 1998), these stay responses would be reinforced following a delay, which varies for each response and is the time from the response to the reinforcer. In addition, stay responding at the first alternative would be reinforced following a delay. Although stay responses at the first alternative also would be reinforced following a delay without a COD, adding a COD makes this delay even longer. Because the delay is longer, the switch reinforcers would have comparatively little effect on stay responses at the first alternative. Although there are other methods of arranging a COD

(see Shahan & Lattal), analyses of each method are similar to the above analysis.

The purpose of the present experiments was to examine whether run lengths and visit durations were functions of the ratio of the likelihoods of stay and switch reinforcement when using a COD. If orderly functions obtained, then a further purpose was to see whether these performances could produce an approximation to composite concurrent performances while using a COD. The general approach was to present one pair of stay and switch schedules. Staying at one alternative was reinforced and switching to the other alternative was reinforced. Over several conditions, the schedules were varied such that, by the end of the experiment, rats experienced several symmetric pairs of stay and switch schedules. When a COD was not used, this approach was easy to implement (MacDonall, 1999, 2000). As just noted, however, a COD produces an interrelationship among the contingencies for stay and switch reinforcement that produces several challenges.

First, consider decomposing a two-alternative concurrent procedure, previously discussed. When presenting just one pair of stay and switch schedules and not using a COD, reinforcing switching is simple. When a switch reinforcer is arranged, the next response at the second alternative is reinforced. To reinforce switching when a COD is used, however, responses at the second alternative continue until the COD elapses and the next response at the second alternative obtains the reinforcer, if arranged. If this is done, then the problem is deciding how to count these responses during the COD at the second alternative. Are they considered stay responses at the second alternative? This seems reasonable, but these stay responses cannot obtain stay reinforcers. Fewer problems arise when decomposing a switch-lever concurrent procedure (Findley, 1958) that uses a COD.

In a switch-lever concurrent procedure, one lever (the stay lever) is always available, and stay responses are reinforced according to one of the two schedules operating. Either schedule can arrange a reinforcer at any time, but that reinforcer can only be obtained when the stimulus associated with that schedule is present. Responding at a second lever (the switch lever) switches stimuli. When a

COD is not used and a reinforcer is arranged at the alternative not in effect, say Alternative 2, that reinforcer is held. When a press at the switch lever produces Alternative 2, then the first response at Alternative 2 obtains the held reinforced. This reinforcer may also reinforce pressing the switch lever following a short delay. As in the two-lever procedure, stay responses at Alternative 1 would be reinforced following a longer delay.

When a COD is used and a reinforcer is arranged at Alternative 2, however, the contingencies are slightly different. The COD begins with a response at the switch lever. The reinforcer for switching to Alternative 2 is delayed because it is delivered by the first response at the stay lever following the COD. As in the two-lever procedure, the first stay response at Alternative 2 after the COD is immediately reinforced. Stay responses during the COD (at Alternative 2) precede the reinforcer by variable delays, depending on when they occurred in the delay interval. As in the two-lever procedure, stay responses at the first alternative would be reinforced following a delay consisting of the COD plus the time taken to move from the stay lever to the switch lever and back to the stay lever, plus the time from the stay response at Alternative 1 to the beginning of the switch.

The contingencies at one alternative of a switch-lever concurrent schedule were used in the first experiment. The first press at the stay lever after the COD could be reinforced according to either the stay or switch schedule. The switch reinforcer would be arranged during the previous visit and, generally, the stay reinforcer would be arranged during the just elapsed COD. To separate stay and switch reinforcers—that is, to allow only the first stay response after the COD to be reinforced according to the switch schedule—the stay schedule began operating when the COD ended. Thus, the first press at the stay lever started the switch schedule, and the stay schedule started when the COD ended. A press at the switch lever stopped both schedules. When a switch reinforcer was arranged, a press at the switch lever started the COD and allowed the first press at the main lever after the COD to deliver the switch reinforcer.

EXPERIMENT 1

METHOD

Subjects

The subjects were 4 female Sprague-Dawley rats obtained from Hilltop Lab Animals Inc. (Scottsdale, PA), which were housed individually in a temperature-controlled colony room on a 14:10 hr light/dark cycle with free access to water. They had previously been used in an Introductory Psychology laboratory section in which undergraduate students shaped lever pressing and reinforced it on small variable-ratio schedules in one-lever operant chambers. After the end of the course, rats were fed unlimited food for several weeks, and then they were deprived to and maintained at 85% of their free-feeding weights. They were approximately 180 days old when the experiment began.

Apparatus

Two operant conditioning chambers measuring 20 cm wide, 20 cm high, and 20 cm long were used. The food cup was centered horizontally on one wall and the center of the 5 cm square opening was 3.5 cm above the floor. The centers of two response levers, 5 cm long, 1 cm high and protruding 1.5 cm into the chamber (Gerbrands, Model G6312), were located 5.5 cm from either side of the vertical centerline of the food cup and 6.5 cm above the floor. A minimum force of approximately 0.3 N operated each lever. A Gerbrands feeder, located behind the food cup, dispensed 45-mg formula A/1 rodent pellets (P. J. Noyes), which are 85% Purina Rodent Chow. Each chamber was located inside a sound- and light-controlled enclosure. During sessions, a houselight mounted on the ceiling of the enclosure operated continuously, and a speaker mounted on the ceiling of the chamber provided white noise. Located in an adjacent room was an IBM compatible computer with hardware (MED Associates) and software (MED-PC®) that controlled contingencies and recorded data.

Procedure

Because lever pressing did not need to be shaped, the rats were placed immediately in the first condition. Table 1 presents the sequence of conditions and the number of sessions in each condition. Pressing either the

stay (left) lever or the switch (right) lever was not shaped—these responses emerged during the first session. Because the rats had not experienced lean reinforcement schedules, however, on the first day the schedules provided twice the rate of reinforcement for staying and switching as noted in Table 1.

When sessions began, stay and switch VI schedules began operating. Stay responses were occasionally reinforced according to the stay schedule. When the stay schedule arranged a reinforcer, it stopped until a stay response obtained that reinforcer; the switch schedule, however, continued operating. Switch responses stopped stay and switch VI schedules and started the 5-s COD: there was no other programmed effect. Switch responses did not deliver a reinforcer and further switch responses had no programmed effect. The next response at the stay lever started the switch VI schedule. The stay VI schedule started after the COD. When the switch VI arranged a reinforcer, the switch schedule stopped. If a switch reinforcer was arranged when a switch response started the COD, the first stay response after the COD obtained that switch reinforcer and restarted the switch schedule.

The VI schedules were comprised of 10 intervals constructed using the constant probability distribution provided by Fleshler and Hoffman (1962). All 10 intervals were randomly sampled without replacement. The houselight and white masking noise were turned on at the beginning of the session and were turned off when the session was ended by the first switch response following the 100th reinforcer. Conditions were continued for at least 20 sessions and until, by visual inspection, there was no systematic upwards or downwards trend in the log of mean run lengths, the log of mean visit durations, and the log ratio of stay-switch reinforcers over the last seven sessions. Typically, data were collected daily.

RESULTS AND DISCUSSION

Data analyses were based on the sums of the data from the last seven sessions. Table 1 presents these sums for the number of stay responses, time at the alternative, time not at the alternative, number of reinforcers for staying, number of reinforcers for switching, number of presses at the switch lever, and

Table 1

For each rat, the sequence of conditions and the number of sessions in each condition. Also presented are the sums over the last seven sessions of the number of stay responses, time at the alternative, time not at the alternative, number of reinforcers for staying, number of reinforcers for switching, number of presses of the switch lever, and number of switches.

Rat	VI schedule value (s) for		Sessions	Stay responses	Time (s)		Reinforcers for		Switch responses	Switches
	Staying	Switching			At the alternative	Not at the alternative	Staying	Switching		
506	320	36	42	8,354	31,592	3,148	82	619	1,522	1,491
	43	128	26	12,804	28,256	625	602	123	356	347
	64	64	25	17,353	27,823	1,886	371	330	1,159	1,139
	128	43	28	14,275	29,865	2,329	178	523	1,488	1,485
	37	224	22	18,797	25,691	444	622	85	389	387
	64	64	26	17,734	27,468	2,127	395	311	1,008	1,000
	224	37	20	15,146	30,034	3,348	108	592	1,685	1,650
	36	320	20	17,487	25,473	671	652	62	341	340
	86	51	21	18,277	28,360	2,615	280	420	1,299	1,259
	51	86	21	16,256	26,746	2,008	485	222	895	880
	36	320	43	17,469	25,453	683	664	47	153	147
	128	43	20	16,793	28,791	4,702	216	484	1,334	1,277
	64	64	26	15,331	27,132	4,090	398	302	908	832
	224	37	22	11,754	29,628	8,182	118	584	2,031	1,846
528	320	36	20	11,503	30,513	8,308	85	615	2,124	1,958
	64	64	20	12,550	26,727	5,185	359	341	1,402	1,286
	43	128	20	17,204	25,759	2,155	546	155	690	639
	37	224	20	17,382	24,719	1,348	610	94	387	366
	86	51	20	14,801	28,279	4,198	323	377	1,197	1,075
	51	86	28	16,499	26,774	2,475	476	232	691	655
	43	128	66	19,668	25,884	1,436	568	148	437	425
	64	64	23	24,253	28,026	2,294	419	293	888	856
	37	224	24	19,305	24,969	1,084	615	89	447	418
	320	36	21	16,793	28,539	6,150	83	617	2,115	1,975
	128	43	21	20,079	27,441	4,695	210	491	1,897	1,749
	224	37	20	14,346	28,093	5,194	118	584	1,939	1,792
	64	64	22	15,300	26,855	3,346	375	325	1,307	1,223
	36	320	27	19,546	24,881	812	661	51	340	328
533	128	43	41	10,046	29,043	5,431	208	493	1,615	1,477
	36	320	33	13,604	25,029	1,605	654	58	356	349
	224	37	22	9,689	29,437	7,831	112	588	1,926	1,816
	64	64	21	9,615	28,280	3,295	387	319	974	934
	224	37	24	10,695	30,706	5,134	117	583	1,644	1,574
	36	320	20	8,640	25,918	1,026	629	77	358	351
	64	64	23	7,658	29,597	2,297	416	285	779	742
	43	128	20	6,590	27,538	1,688	580	129	450	440
	320	36	21	9,527	32,924	5,167	95	605	1,582	1,546
	37	224	22	9,542	26,509	996	622	83	284	277
539										

number of switches. The time at the alternative began with the first press at the stay lever and ended with the first press at the switch lever. The time not at the alternative began with the first press at the switch lever and ended with the first press at the stay lever. The number of switches was the number of times the press at the switch lever was preceded by a press at the stay lever; thus, the number of switches excluded additional presses after the first press at the switch lever.

Because the COD transforms the switch

contingency into delayed reinforcement of switching and immediate reinforcement of staying at the switched-to alternative, the first analysis determined whether run lengths and visit durations were functions of stay and switch reinforcement. Figure 1 shows that the logarithms (log) of the mean run length and of the mean visit duration were approximately linearly related to the log of the ratio of the rate of obtaining stay reinforcers divided by the rate of obtaining switch reinforcers. The mean run length was the number of stay

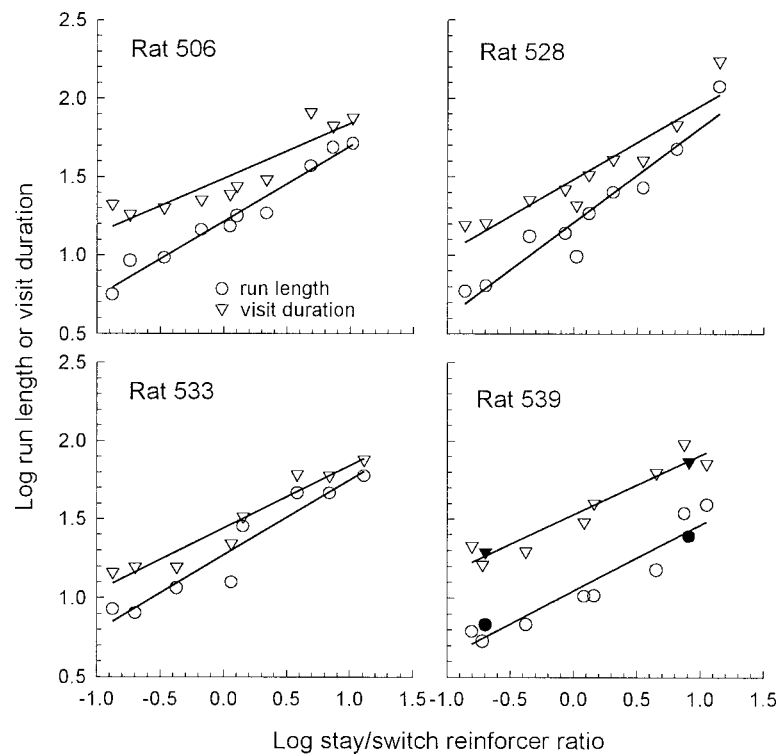


Fig. 1. The log of the mean run length and log of the mean visit duration plotted as a function of the log of the ratio of the rates of reinforcement (stay-switch). The straight lines are the best fitting lines by the local model (Equation 1). The filled data points are replications.

responses divided by the number of switches. Similarly, the mean visit duration was the time at the alternative divided by the number of switches. Table 2 presents fits of these data by the local model (Equation 1) which are good to excellent ($r^2 > .83$), and the standard errors of estimate are small. Slopes (k_1) ranged

Table 2

Fits by the local model (Equation 1) to the run lengths and visit durations and stay and switch reinforcers per visit.

Rat	k_1	SE	$\log m_1$	SE	r^2	df
Run lengths						
506	0.48	0.03	1.21	0.02	.96	8
528	0.60	0.06	1.21	0.04	.92	8
533	0.48	0.06	1.27	0.04	.92	6
539	0.42	0.05	1.04	0.03	.91	8
Visit durations						
506	0.35	0.06	1.49	0.04	.83	8
528	0.47	0.06	1.48	0.04	.87	8
533	0.40	0.04	1.44	0.03	.93	6
539	0.38	0.04	1.53	0.03	.93	8

from 0.35 to 0.60, and y-intercepts ($\log m_1$) ranged from 1.04 to 1.53. Within rats, slopes for run lengths were consistently greater than slopes for visit durations. Although the fits are good to excellent and the relation is approximately linear, obtained log run length and log visit duration are slightly under the best-fitting line when the rate of stay reinforcers approximately equaled the rate of switch reinforcers; that is, when the log stay-switch reinforcer ratio was approximately zero. They are above the best-fitting line when the rates of stay reinforcers are very different than the rates of switch reinforcers; that is, when the log stay-switch ratio was closer to plus or minus one. Log, exponential, and linear fits did not produce consistently better results. This pattern of responding, although less extreme, is consistent with the "fix and sample" pattern found following extended exposure to concurrent schedules (Baum, Schwendiman, & Bell, 1999). Behavior fixes at the richer alternative; that is, long runs of responding at the richer alternative,

are occasionally interrupted by brief samples at the lean alternative. In Figure 1, the richer alternatives are to the right of the 0 point on the x -axis, and the leaner alternatives are to the left of the 0 point.

Next, concurrent VI VI performance was synthesized from the performances maintained by one pair of stay and switch schedules using methods described in detail by MacDonall (1998, 1999). First, the conditions were grouped into symmetric pairs, such that the value of the stay schedule in one condition equaled the value of the switch schedule in the symmetric condition. For example, the condition VI 43 s for staying and VI 128 s for switching was paired with the condition VI 128 s for staying and 43 s for switching. Second, within each pair, the condition that was presented first was considered Alternative 1. If this procedure were followed for Rat 533, it would have produced a restricted range along the x -axis. Consequently, the first condition of the third pair (VI 38 s and VI 224 s) became Alternative 2 rather than Alternative 1. Two conditions for Rat 539 were replicated and the data from both replications were used in the synthesis and were Alternative 1. Third, the data from these groups of conditions were fitted by the generalized matching law (Baum, 1974) expressed as per visit performance (MacDonall, 1998, 1999) by dividing behavior and stay and switch reinforcers at each alternative by the number of switches to the other alternative, which can be expressed as,

$$\log \left(\frac{B_1/C_2}{B_2/C_1} \right) = a \log \left[\frac{(Rt_1/C_2) + (Rw_1/C_1)}{(Rt_2/C_1) + (Rw_2/C_2)} \right] + \log b. \quad (2)$$

The two fitted parameters are a , which is interpreted as behavioral sensitivity to reinforcer allocation, and $\log b$, which is interpreted as bias towards one alternative that is not related to reinforcer allocation. The other symbols are as in Equation 1. Figure 2 shows that the log ratio of run length and the log ratio of visit duration were approximately linearly related to the log of the composite reinforcer ratio. Table 3 presents the fits by Equation 2, which were excellent ($r^2 > .93$) and the stan-

dard errors of estimate were small. Slopes (a) ranged from 0.70 to 1.23. Within rats, slopes for ratio of run lengths were consistently higher than the slopes for ratio of visit durations. There were no consistent biases, although there was a tendency for a bias towards Alternative 1.

An alternative model of concurrent performance (MacDonall, 1999, 2000), based on the local model (Equation 1), simply takes the ratio of the local model applied to both alternatives, producing,

$$\log \left[\frac{(B_1/C_2)}{(B_2/C_1)} \right] = k' \log \left(\frac{Rt_1/Rw_2}{Rt_2/Rw_1} \right) + \log m'. \quad (3)$$

The two fitted parameters are k' , which is behavioral sensitivity to stay and switch rates of reinforcement, and is assumed to be equal to k_1 and k_2 , and $\log m'$, which is the bias towards one alternative, and is the ratio of the propensities to response at each alternative, $\log (m_1/m_2)$. The other symbols are as in previous equations.

The last analysis determined whether the present data could synthesize concurrent performance using the local model applied to concurrent performance (Equation 3). The conditions were paired as just described. Figure 3 shows that log ratio of run lengths and log ratio of visit durations were approximately linearly related to the log of the ratio of the ratios of stay and switch rates of reinforcement. Table 4 shows the fits of these data by Equation 3, which were excellent ($r^2 > .93$) with generally small standard errors of estimate. Slopes (k') ranged from 0.35 to 0.61. Within rats, slopes for ratios of run lengths were greater than slopes for ratios of visit durations.

The local model (Equation 3) and the generalized matching law (Equation 2) are related mathematically. When using standard concurrent procedures, it can be shown that the slopes of the fits by the generalized matching law are twice the slopes of fits by the local model applied to concurrent performances (MacDonall, 1999). Previous research, which did not use a COD, found this doubling (MacDonall, 1999, 2000). Comparing the slopes in Tables 3 and 4 shows this doubling

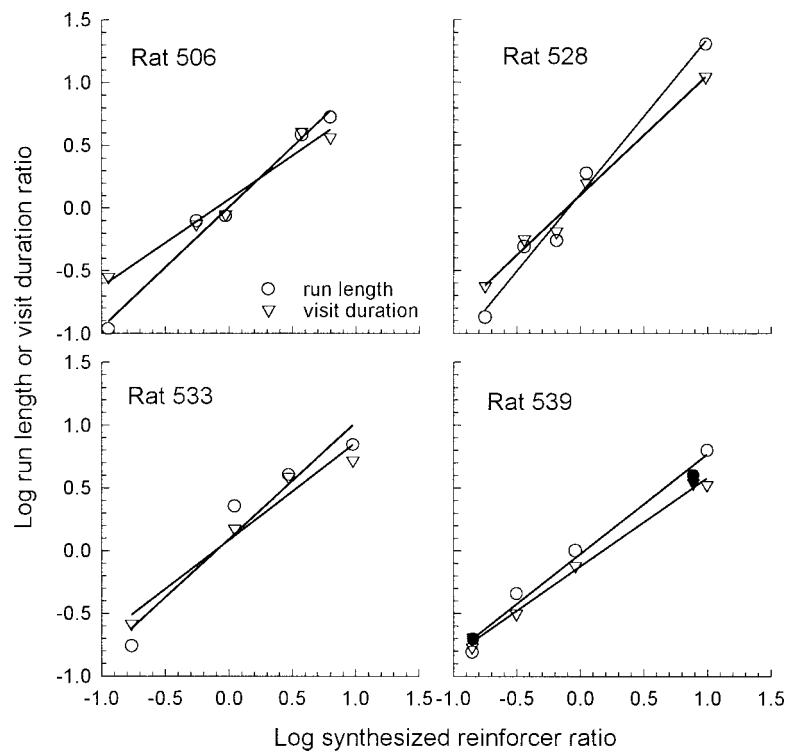


Fig. 2. The log of the ratio of the run lengths and log of the ratio of visit durations plotted as a function of the log of the composite reinforcer ratio. The straight lines are the best fitting lines by the per visit version of the generalized matching law (Equation 2). The filled data points are replications.

is also closely approximated when using a COD. As noted previously (k_1), the slope of fits by the local model to performance maintained by one pair of stay and switch schedules (Equation 1) equals k' , the slope of fits by the local model applied to concurrent per-

formance (Equation 3). Previous research, which did not use a COD, found this equality (MacDonall, 1999, 2000). Comparing the slopes in Tables 2 and 4 shows that, when a COD was used, for each rat k_1 approximately equals k' .

The results of Experiment 1 indicate that run lengths and visit durations are power functions of the ratio of the rates of stay and switch reinforcement when using a COD. These results replicate and extend previous results from experiments that did not use a COD (MacDonall, 1998, 1999, 2000). Thus, it appears that generally run lengths and visit durations are power functions of the ratio of the rates of stay and switch reinforcement.

Because the generalized matching law (Equation 2) fitted these results, it suggests that the analysis of concurrent schedules in terms of reinforcement for staying and reinforcement for switching may apply to the most common concurrent procedures; that is, those using a COD. It appears that concurrent performances may be comprised of

Table 3

Fits by the generalized matching law (Equation 2) to the composite response ratios, time ratios, and reinforcer ratios. The composite ratios were obtained from the per visit response, time, and reinforcer data.

Rat	a	SE	$\log b$	SE	r^2	df
Run lengths						
506	0.96	0.07	0.01	0.04	.98	3
528	1.23	0.10	0.11	0.06	.98	3
533	0.93	0.17	0.09	0.12	.93	2
539	0.80	0.05	-0.03	0.03	.99	4
Visit durations						
506	0.70	0.08	0.07	0.05	.96	3
528	0.96	0.06	0.10	0.04	.99	3
533	0.78	0.11	0.08	0.08	.96	2
539	0.71	0.02	-0.13	0.02	1	4

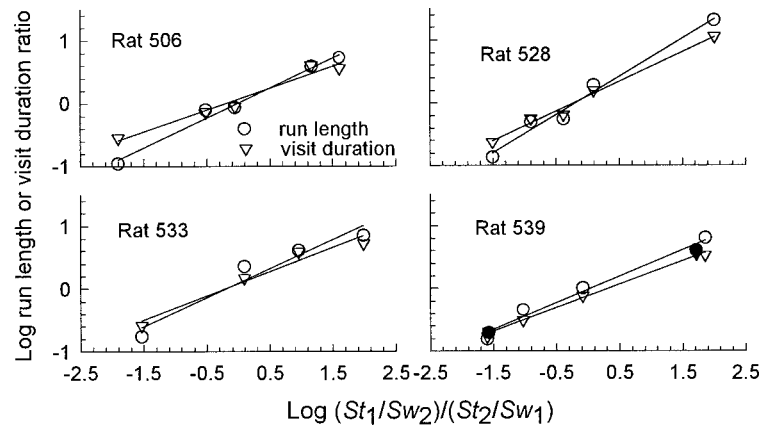


Fig. 3. The logs of the ratios of run lengths and the logs of the ratios of visit durations plotted as a function of the logs of the ratios of the rates of stay and switch reinforcement. The straight lines are the best fitting lines by the local model applied to concurrent performance (Equation 3). The filled data points are replications.

two independent performances maintained by two sets of contingencies that are joined by the changeover response.

Concurrent performances were synthesized even though some of the detailed contingencies in the present experiment were different from those in concurrent procedures. Specifically, in a concurrent schedule that uses a COD, reinforcers for switching from Alternative 1 to Alternative 2 are delivered following a stay response at Alternative 2 which was several seconds after the response at Alternative 2 that switches alternatives; the stay response that delivered the switch reinforcer was also immediately reinforced. In the present synthesis, however, there was no reinforcement for stay responding at Alternative 2 because there was no Al-

ternative 2. Rather, reinforcers delivered for switching to Alternative 2 reinforced stay responses at the beginning of a visit at Alternative 1. Because concurrent performances were synthesized in terms of good fits by the generalized matching law, it appears that these differences in the contingencies for delayed reinforcement for stay responding during the COD were not critical for producing these good fits. The contingencies for the delayed reinforcement for stay responding, however, may be important for reproducing other quantitative aspects of concurrent performances, such as the increase in slope produced by a COD.

A COD appears to have two effects on concurrent performance (Pliskoff, 1971; Shull & Pliskoff, 1967; Temple, Scown, & Foster, 1995). First, the COD decreases the frequency of switching from one alternative to the other, which in the present procedure (in which only one alternative is used) increases k_1 , the propensity to respond at an alternative. Second, the COD increases the slope in fits by the generalized matching law. Considering the just-discussed mathematical relation among the generalized matching law and the local model, the increased slopes in fits by the generalized matching law mean increased slopes in fits by Equation 1.

Because the present experiment did not include conditions without a COD, it cannot be determined whether the COD increased sensitivity and the propensity to respond. MacDonall (2000) previously exposed rats to

Table 4

Fits by the local model applied to concurrent performance (Equation 3) to the composite response ratios, time ratios, and reinforcer ratios.

Rat	k'	SE	$\log m'$	SE	r^2	df
Run lengths						
506	0.48	0.03	0.01	0.04	.98	3
528	0.61	0.05	0.11	0.06	.98	3
533	0.46	0.09	0.09	0.12	.93	2
539	0.42	0.03	-0.03	0.04	.98	4
Visit durations						
506	0.35	0.04	0.07	0.05	.96	3
528	0.47	0.03	0.10	0.04	.99	3
533	0.39	0.06	0.08	0.08	.96	2
539	0.37	0.01	-0.13	0.02	1	4

one pair of stay and switch schedules. The procedure, however, was based on the decomposition of a two-lever procedure; that is, switching was reinforced following a press at the other lever, as opposed to the current procedure in which switching is reinforced following a stay-lever response (following the COD). This procedural difference makes comparisons between results from these two experiments inappropriate.

The purpose of Experiment 2 was to compare within rats the effects of a 5-s COD on run lengths and visit durations. One approach is to expose rats to several conditions of a procedure that includes a COD and several conditions of a procedure that does not include a COD, fit the data from each procedure by Equation 1, and compare the propensity to respond (k_1). This approach compares fitted parameters rather than behavior. Instead, rats were exposed to a two-component multiple schedule with stay and switch schedules in each component and a COD in only one component. Then, absolute run lengths (and visit durations) were compared between components. The stay and switch schedules stopped from the time a reinforcer was arranged until it was obtained. Consequently, it could take longer, on average, to obtain the reinforcer in the COD component, which could lower the reinforcement rate. To try to keep the stay reinforcement rates the same, the stay and switch VI schedules were 2 to 4 s shorter in the component with the COD.

EXPERIMENT 2

METHOD

Subjects

The subjects were four male Sprague-Dawley rats obtained from Hilltop Animal Labs when they were 90 days old. They were housed individually in a temperature-controlled colony room on a 14:10 hr light/dark cycle with free access to water. For 2 weeks after delivery they were fed unlimited amounts of rat chow. They were then fed 5 gm of food daily until their weights were 85% of their free-feeding weights, at which time they were fed sufficient food to maintain those weights. Then, lever pressing was shaped using the method of successive ap-

proximations employed by students in an Introductory Psychology laboratory section. After this, the rats were exposed to small fixed-ratio (FR) schedules for several sessions. After three months, during which time they were maintained at their 85% weights, they entered the present experiment.

Apparatus

Two operant conditioning chambers measuring 30.5 cm wide, 27 cm high, and 25 cm long were used. On one 30.5 cm wide wall were three retractable response levers 9 cm apart, on center, and horizontally 9.5 cm above the floor. Only the two outside levers were available during this experiment. A 24-VDC stimulus light was centered approximately 9 cm above each lever. The food cup, a 5 cm square opening located 3 cm above the floor, was centered horizontally on the opposite wall. Reinforcers consisted of 45-mg formula A/1 pellets (P. J. Noyes), which are 85% Purina Rodent Chow.

Procedure

Each session consisted of a two-component multiple schedule. Whether a session began with a COD or no-COD component was random. After the first component, components alternated until they were presented five times each. The procedure in the component signaled by white noise included a 5-s COD, and the procedure in the component signaled by the light was identical except it did not include a COD. Components ended following the first switch response following 5 min in that component and were separated by a 1-min blackout. For Rats 651 and 652 in Condition 3, components ended following the first switch response after 2.5 min in that component. Because the VI schedules stopped when a reinforcer was arranged during a COD and restarted at reinforcement following the COD, a COD reduced the reinforcer rate. To keep the obtained reinforcer rate in the two components approximately equal, the mean duration of the VI stay and switch schedules in the Light Component (no COD) were 2 to 4 s longer than the durations in the Noise (COD) Component. In the Light Component, pressing the stay (left) lever started both stay and switch VI schedules and obtained a stay reinforcer if one was arranged. Pressing the switch (right) lever

Table 5

For each rat, the sequence of conditions and the number of sessions in each condition. In each condition, the stay schedule in a component equaled the switch schedule in the same component. Also presented for the no-COD and COD components of the multiple schedule are the sums over the last five sessions of the number of stay responses, number of switch responses, number of switches, time at the alternative, number of reinforcers for staying, and number of reinforcers for switching.

Rat	Con- di- tion	VI schedule value (s)		No COD						COD									
				Responses		Switch- es	Time (in s) in stay	Reinforcers		Responses		Switch- es	Time (in s) in stay	Reinforcers					
		No		Stay	Switch			Stay	Switch	Stay	Switch			Stay	Switch				
		COD	COD																
651	1	64	60	2,929	443	414	7,766	118	85	2,009	112	97	9,578	134	43				
	2	64	60	2,368	407	399	7,919	114	85	2,781	92	83	13,839	202	37				
	3	30	28	2,073	406	381	3,742	118	88	4,279	69	63	8,720	279	30				
652	1	64	60	2,074	670	531	7,047	110	91	1,951	289	208	8,432	123	80				
	2	64	60	1,484	389	340	8,001	120	87	1,248	208	140	7,936	110	65				
	3	30	28	774	126	117	4,917	134	69	3,692	64	53	20,509	536	29				
653	1	64	60	8,897	956	908	7,184	118	96	13,475	100	96	10,768	155	50				
	2	64	60	9,819	1,013	934	7,039	105	100	10,940	176	160	8,409	125	67				
	3	32	30	8,234	801	767	7,329	219	173	11,367	196	185	7,941	245	101				
654	1	64	60	1,978	543	510	7,084	110	95	2,312	278	256	7,883	116	89				
	2	64	60	2,220	600	559	7,204	107	95	2,204	316	294	8,019	122	89				
	3	32	30	1,859	528	493	7,276	215	165	2,099	285	224	7,514	196	122				

stopped both schedules. A switch reinforcer was not obtained if one was arranged. Rather, that switch reinforcer was delivered following the next press of the stay lever. If stay and switch reinforcers were arranged, the first press at the stay lever would obtain the switch reinforcer and the next press would obtain the stay reinforcer. In the Noise Component, the contingencies differed in that a press at the switch lever started a COD. Stay or switch reinforcers could not be obtained by presses at the stay lever until after the COD, at which point the contingencies were the same as in the Light Component.

The VI schedules were comprised of 10 intervals constructed using the constant probability distribution provided by Fleshler and Hoffman (1962). All 10 intervals were randomly sampled without replacement. Conditions remained in effect until there was no consistent upward or downward trend in run lengths or visit durations in session averages in each component for five consecutive sessions. Then there was one session of extinction, which will be reported elsewhere. Table 5 presents the sequence of conditions and the number of sessions each condition was in effect. Because the rats were already lever pressing in the present apparatus, each rat

began in the first condition listed in Table 5, which remained in effect for at least 30 sessions.

RESULTS AND DISCUSSION

Data analyses were based on the data from the last five sessions of each condition. Table 5 also presents, for the Light and Noise Components, the sums over the last 5 days of the number of stay and switch responses, the number of switches, the total time at the stay lever; that is, the time from the first press at the stay lever in a run to the first press of the switch lever ending a run, and the number of reinforcers for staying and for switching.

Before addressing the main question for this experiment, it must be seen whether the rates of stay reinforcement were approximately the same in the COD and no-COD components. Figure 4 shows that in all 12 conditions the rate of stay reinforcement in the COD component was approximately the same as the rate in the no-COD component. As expected, the obtained rate of reinforcement under VI 32 s (or VI 30 s) was approximately twice the rate under VI 64 s.

The question for this experiment was whether CODs affect run lengths and visit durations. Figures 5 and 6 show, for each rat in

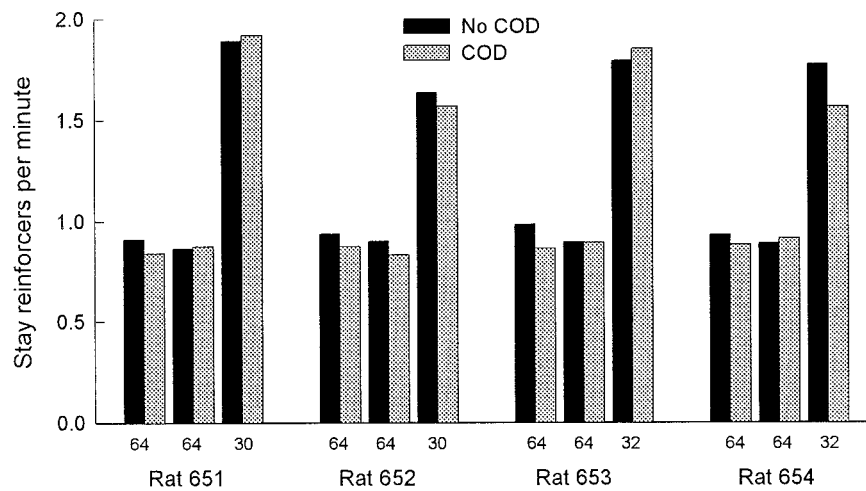


Fig. 4. The rate of stay reinforcement in each condition for each rat. The stay schedule of reinforcement in the COD component programmed for each condition is shown below each pair of bars.

each condition, that the mean run lengths and mean visit durations were longer in the component with a COD. The errors bars, representing the standard deviation, show that these differences were reliable. In all 12 comparisons, the mean run length and visit duration were longer when a COD was used, and there was no overlap among the error bars. Table 5 shows that the increased run lengths and visit durations produced by the COD were a joint result of decreased switching and increased responding or time at the

stay lever. In all 12 comparisons, there were fewer switches in the COD component. In 8 of the 12 comparisons, there were more stay responses in the COD component. In 11 of 12 comparisons, the total time at the stay lever was longer in the COD component. For the one exception, the difference was less than 1%. Thus, in a direct comparison within rats and within the same sessions, a COD produced longer run lengths and visit durations and appeared to do so by increasing stay responding while decreasing switching.

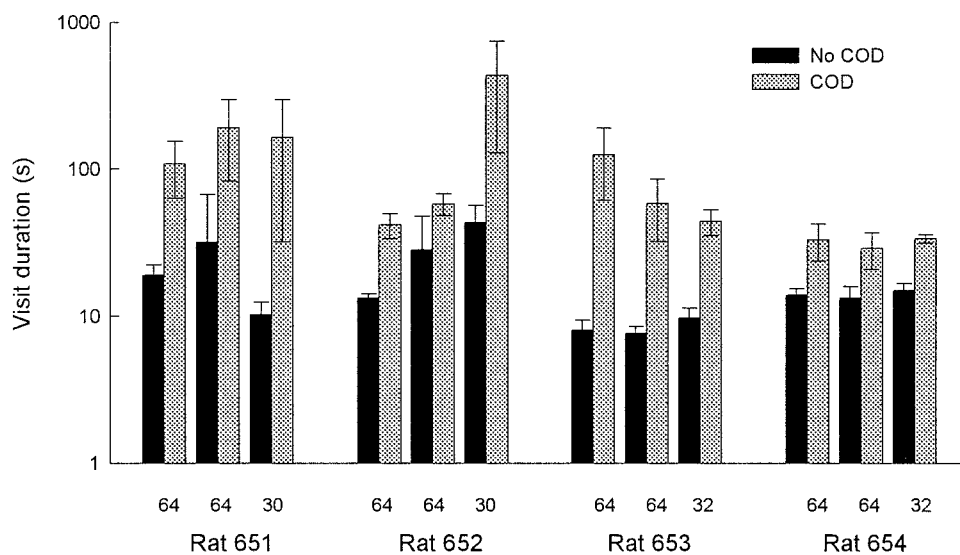


Fig. 5. The mean visit durations for each condition for each rat. The vertical lines represent the standard deviations. Because the y-axis is logarithmic, the error bars are asymmetrical.

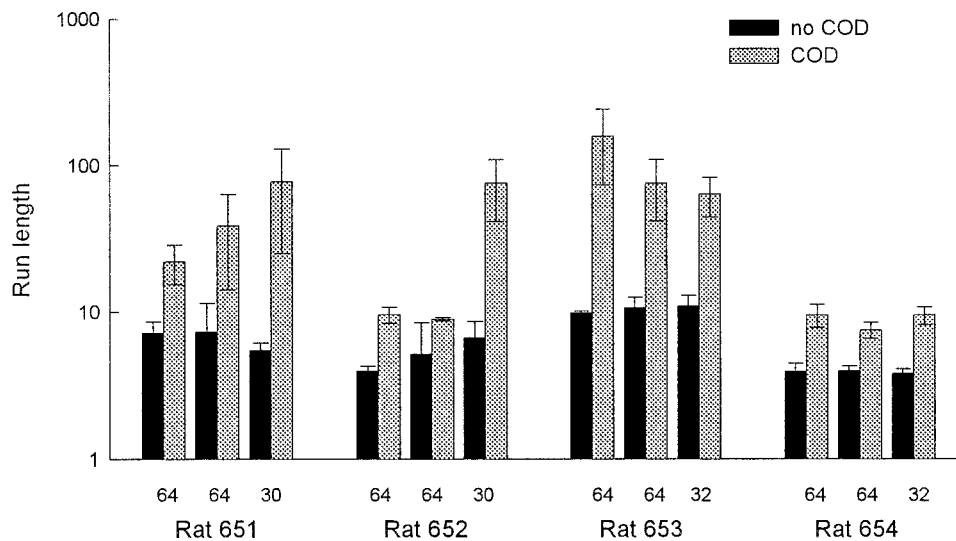


Fig. 6. The mean run lengths for each condition for each rat. The vertical lines represent the standard deviations. Because the y-axis is logarithmic, the error bars are asymmetrical.

GENERAL DISCUSSION

The results of the present experiments combined with previous experiments suggest that the local model applied to concurrent performance is an alternative to the generalized matching law for modeling concurrent performance. Why bother developing an alternative to the generalized matching law, and why should the alternative view concurrent performance as two independent performances joined by the changeover response? The generalized matching law is a simple and robust mathematical expression that accounts for a wide variety of experimental results from concurrent choice procedures. It is an excellent model as long as investigators focus on choice and use symmetric pairs of stay and switch schedules, as when using one VI schedule for each alternative. Certainly, there is no benefit of using the local model applied to concurrent performance over the generalized matching law when modeling simple concurrent procedures. In fact, because of the algebraic relation between the local model applied to concurrent performance and the generalized matching law, there can be no quantitative advantage in using the local model. Because the generalized matching law is well known it should be used.

When it comes to analyzing other aspects of concurrent performance, however, the lo-

cal model may have advantages. For example, the local model may be better able to account for local behavior within the choice performance, such as the rate of changing alternatives, or its reciprocal—visit duration—because the rate of changing alternatives, or visit duration, is found in the local model. Viewing concurrent performance as two independent performances joined by the changeover response, the rate of changing over, or visit duration, is an integral part of the model, and it may be possible to develop a quantitative model that accounts for variables that affect changeover rates. For example, larger changeover delays, increased travel distances, increased FR changeover requirements, and punishing changeovers all reduce the rate of changing over.

As the preceding analyses indicate, concurrent schedules involve complex contingencies which are made more complex because two different procedures, two-lever (Herrnstein, 1961) and switch-lever procedures (Findley, 1958) are used seemingly interchangeably. There are many possible alternative approaches to modeling concurrent performance. For example, one might try to develop a different model for each procedure, one for the two-alternative procedure (Herrnstein) and one for the switch-key procedure (Findley). Indeed, it may be simpler to conceptualize different models for the different

procedures. Having two different models for procedures that are generally thought to be equivalent, however, adds to the complexity of the field rather than reducing the complexity. In considering an alternative to the generalized matching law, it seemed appropriate to develop a model based on the contingencies as experienced by the subject. The subject experiences being at an alternative and faces the choice of either staying and responding or switching. From this develops the local model, which holds that run lengths and visit durations are power functions of the ratio of the rates of reinforcement for staying and switching (Equation 1). Although the local model may be difficult to grasp, this may result from the long standing confounding of stay and switch reinforcement in conceptualizations of concurrent choice procedures. Regardless of the ultimate success of the local model, the model and resulting data do indicate the importance of considering stay and switch reinforcement (MacDonall, 1988, 1998, 1999, 2000).

The approach of the local model of concurrent performance is consistent with the general approach Herrnstein (1961) used in developing the matching law. Herrnstein started with the idea that absolute response strength, measured by response rate, was a function of reinforcer rate. While at the time this relation could be either linear or curvilinear, the matching law was conceptualized as the proportion of the absolute response strengths of the responses at two alternatives equaling the proportion of the reinforcer rates obtained at those two alternatives. The generalized matching law relies on the ratio, rather than the proportion, of those variables (Baum, 1974). The local model proposes that absolute response strength, as measured by run length and visit duration, is a function of the ratio of stay and switch reinforcement. Thus, the local model applied to concurrent performance is an extension of the approach used by Herrnstein, with absolute response strength measured as run length or visit duration and not response rate. The fact that run lengths and visit durations are positively

related to rates of reinforcement for staying and negatively related to rates reinforcement for switching is consistent with the proposal that run lengths and visit durations are measures of response strength. It remains for future research to verify the view that run length and visit duration are measures of absolute response strength.

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